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Technical Report

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**REVEAL:
Receiver Exploiting Variability in Estimated Acoustic Levels
FY09 Year End Report**

by
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ABSTRACT

The long-term goal of the REVEAL project is to develop a signal processing structure that exploits available knowledge of the environment and of signal and noise variability induced by the environment. The research is directed toward passive sonar detection and classification, continuous wave (CW) and broadband signals, shallow water operation, both platform-mounted and distributed systems, and frequencies below 1 kHz.

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The ideas behind the REVEAL project were those of the late Leon H. Sibul, Professor of Acoustics and Electrical Engineering and Senior Scientist at the Applied Research Laboratory at Penn State. Leon was always interested in getting the physics of underwater acoustics into the signal processor, and he had a lot of ideas regarding how to do that. He was a great mentor to me and to the students. We are grateful for the opportunity to work for him and we miss his enthusiasm and leadership.

The late Dr. Nirmal Bose, HRB Professor of Electrical Engineering at Penn State, played a significant role in developing and injecting rigor into the project. He too is missed.

All of the credit for what we accomplished is due to the students who contributed so much of their time and energy: Jeff Ballard (MS Acoustics, 2007); Jeremy Joseph (MS Acoustics, 2009); Brett Bissinger, John Camin, Colin Jemmott, and Alex Sell.

OBJECTIVES

The objectives for FY09 were to:

- Evaluate the classification performance of a composite Likelihood Ratio (LR) receiver that incorporates model-based signal parameter probability distribution functions (pdfs).
- Develop the structure and evaluate classification performance of a divergence or distance-based classifier based upon the Hellinger distance (HD).
- Use data from the SWellex-96 experiment (shallow and deeper sources towed away from a bottomed line array in shallow water) to compare the classification performance and robustness to mismatch of the LR and HD processors.
- Use data from the 1996 Strait of Gibraltar Acoustic Monitoring Experiment (SGAME) to evaluate the capability of the LLR to classify source depth using probabilistic environment and signal parameter descriptions.
- Investigate the impact of correlated data or detection statistics on processor performance.
- Investigate the ability of a rough surface PE acoustic propagation code to predict received signal parameter variability using ocean surface and volume parameter variability.

APPROACH

Passive sonar systems sometimes have difficulty distinguishing targets of interest from interference or noise sources, especially in areas where shipping traffic is heavy. The hypothesis underlying the REVEAL project is that source classification can be aided by utilizing knowledge of the acoustic environment. For example, Figure 1 shows that the received signal amplitude probability density functions (pdfs) are different for near-surface and near-bottom acoustic sources. This is primarily due to the different propagation paths between the sources and the receiver. The receiver can take advantage of this difference to classify the source depth by predicting the received signal statistics for different source locations and propagation paths and comparing them to the measured signal statistics. Figure 2 depicts a functional block diagram of the REVEAL processor architecture for accomplishing this.

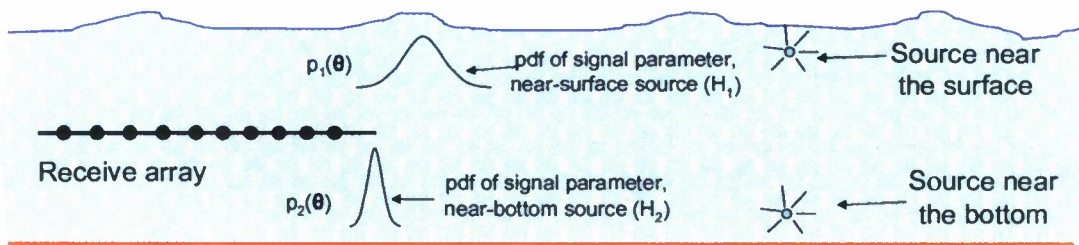


Figure 1: Source depth classification is one possible application of the statistics-based signal processing architecture under development in the REVEAL project. Correct classification would result from comparing signal parameter probability density functions (pdfs) calculated using knowledge of the ocean environment with pdfs derived from received signals.

The REVEAL project Principal Investigator is Dr. Lee Culver, Senior Research Associate at the Applied Research Lab and Associate Professor of Acoustics in the Graduate Program in Acoustics. Dr. N. K. Bose, HRB-Systems Professor of Electrical Engineering at Penn State, provides support in signal processing, information theory, and detection and estimation. Four graduate students contributed to the REVEAL project in FY09. Colin Jemmott earned the MSEE degree from Penn State in May 2008 and in October 2009 advanced to candidacy for the PhD in Acoustics. Jeremy Joseph earned the MS Acoustics

in August 2009. Brett Bissinger earned the MSEE degree from Penn State in October 2009. Alex Sell is a second year acoustics graduate student and working toward the PhD degree.

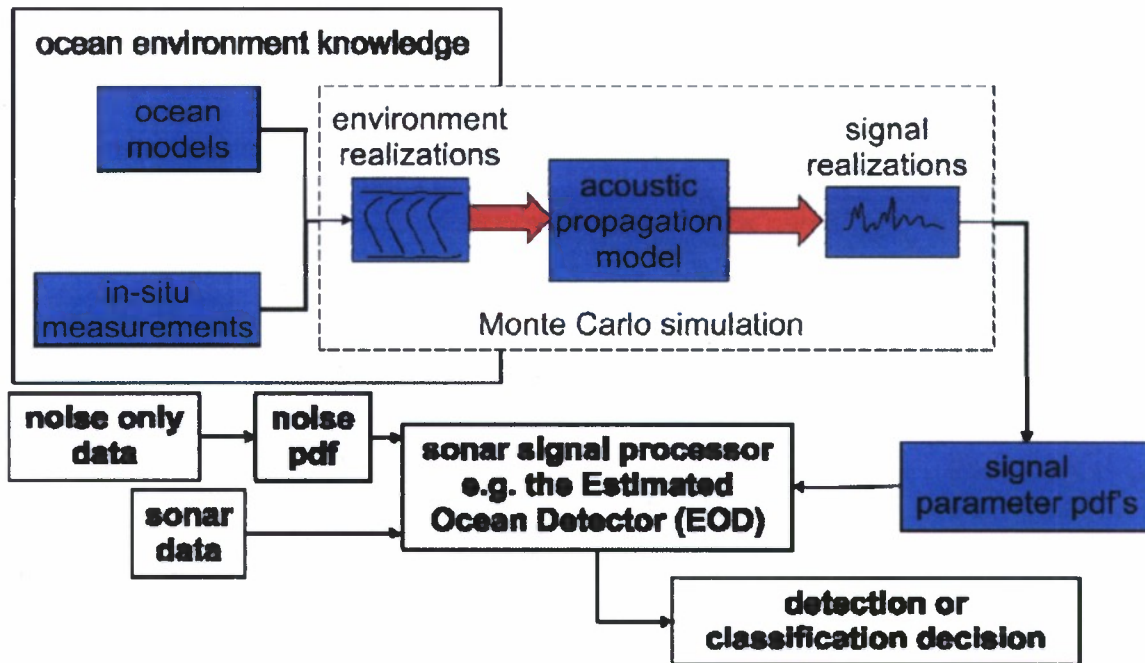


Figure 2: Functional block diagram of the REVEAL processor, in which available environmental information (time- and location-dependent models, in-situ measurements, temporal and spatial variability) is used with Monte Carlo simulation and an acoustic propagation code to produce an ensemble of received signals from which statistics are estimated and used to classify signals.

WORK COMPLETED

Two tasks were completed in FY09: (1) development of a passive underwater acoustic signal classifier based upon the minimum Hellinger distance and (2) a simulation study of the effects of ocean surface variability on received signal statistics using rough surface parabolic acoustic propagation code. A minimum divergence classifier compares the divergences (or distances) between the probability density functions (pdfs) of the received signal and predicted pdfs corresponding to different classes, choosing the class whose pdf has the smallest divergence from the received signal. This method of classification is known as statistical distance-based classification. It has been used in estimation problems (Beran, 1977) and adapted to classification applications (Donoho and Huo, 1977). Other statistical distance measures include the Kullback-Leibler and the Battacharyya divergences. However, the Hellinger distance offers the following desirable properties or metrics: non-negativity, identity, symmetry and triangle inequality.

The suitability of the Minimum Hellinger Distance Classifier (MHDC) is described in Brett Bissinger's MSEE thesis (Bissinger, 2009). Figure 3 is a plot of the distance between the true pdf and incorrect pdfs calculated using the symmetric Kullback-Leibler and Battacharyya distances and the MHDC. It can be seen that the MHDC has the sharpest minimum. This is useful in classification because small differences between pdfs will show the most difference.

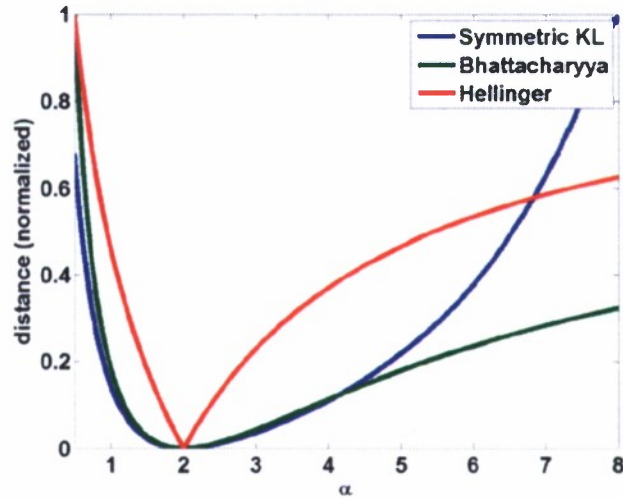


Figure 3: Difference between the true and incorrect pdfs (parameterized by α) calculated using three difference divergence measures. (from Bissinger, 2009)

Simulation was used to compare the binary MHDC with the classic likelihood ratio (LR) processor, which is an efficient estimator (i.e. the Cramer-Rao bound can be achieved). The MHDC also exhibits efficiency, although asymptotically (Lindsay, 1994). Receiver operating characteristic (ROC) curves were used to quantify performance. The MHDC was found to perform as well as the LR processor if the predicted pdfs are accurate and there are sufficient data. When the data are contaminated by outliers, the MHDC provides more robust performance, as is shown in Figure 4. Finally, MHDC and LR performance were found to be comparable for actual ocean acoustic data from the SWellex-96 experiment.

As documented in Joseph's MS thesis (Joseph, 2009), the rough surface PE simulation study focused on received signal amplitude and frequency statistics. The effects of a time-varying rough surface on received signal spectra have been well-studied, e.g. Roderick and Cron (1970), Eckart (1953) and Chuprov (1978) to name a few, but a complete solution that fully describes these effects has not been advanced. In particular, the statistics of the frequency spectra had not been investigated. Received signal amplitude statistics have been investigated, but ability of an acoustic propagation code to predict received signal statistics in a shallow water environment had not been investigated.

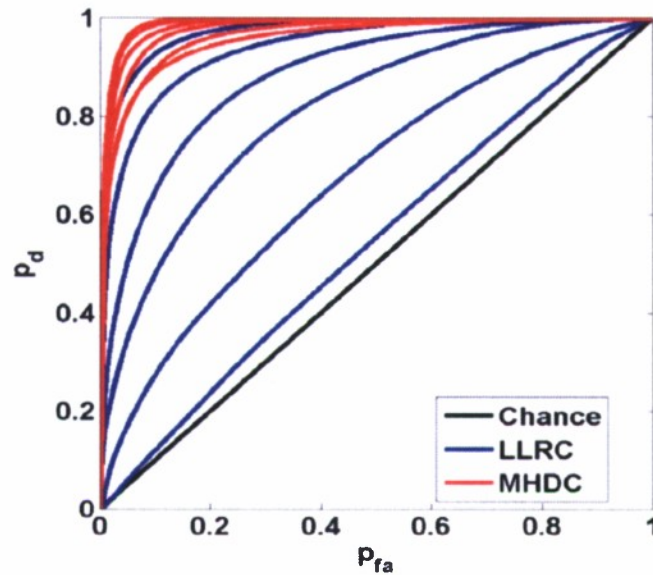


Figure 4: Performance of the Minimum Hellinger Distance Classifier (MHCD) and Log Likelihood Ratio Classifier (LLRC) with outliers at $x=6$ and various contamination levels. LLRC performance degrades sharply with increasing contamination. (from Bissinger, 2009)

An acoustic propagation code based upon an approximation to the acoustic wave equation that results in a parabolic equation (PE) was chosen for this work because it is capable of modeling forward propagation with rough surface with reasonable computation times. A version of Collins' range-dependent acoustic model (RAM) (Collins, 1993) modified to include rough surface effects (Rosenberg, 1999) was selected. A series of rough surfaces were constructed to model the temporal evolution of scattering that occurs as the surface evolves. Using a closed-form model for the ocean surface wave height spectrum, realizations of the ocean surface like that shown in Figure 5 were constructed. Temporally-correlated realizations were constructed using the gravity wave dispersion relation, which relates temporal frequency to spatial wave number, to produce sequences of transmission loss like that shown in Figure 6, from which the received signal histograms shown in Figure 7 were computed.

RESULTS

The most important FY09 result was finding that the MHDC classifier performed as well as the LR classifier when the class models were exact, and provided more robust performance when contamination was present. This finding showed that there are at least two processors (LR and MHDC) that are capable of using received signal statistics to aid in target classification, leaving prediction of the received signal statistics as the remaining challenge for the REVEAL project.

IMPACT/APPLICATIONS

The results of this research will enable a new passive sonar classifier aid that takes advantage of knowledge of medium.

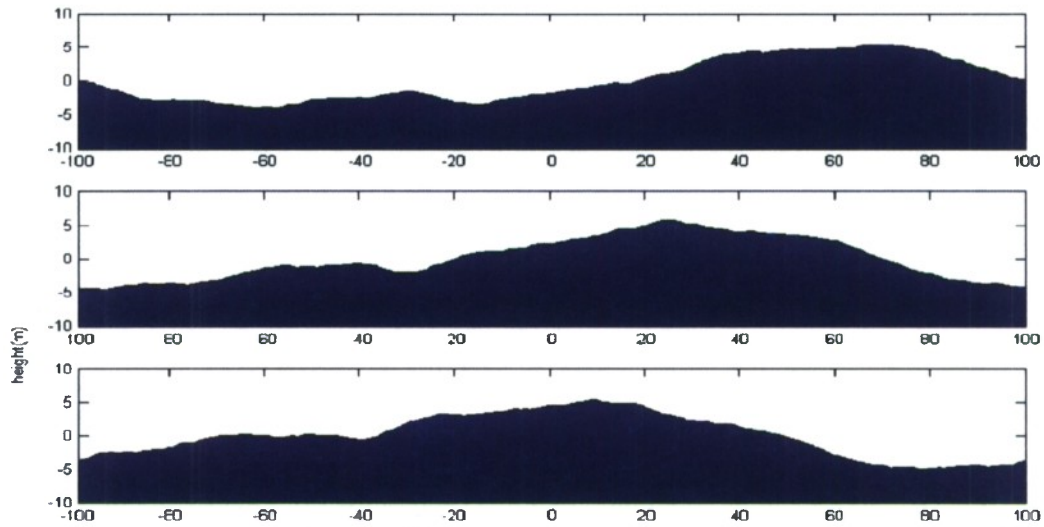


Figure 5: Sequence of wave height profiles constructed for a wind speed of 15 m/s. Horizontal axis is distance in meters. Wave propagation is right to left. (from Joseph, 2009).

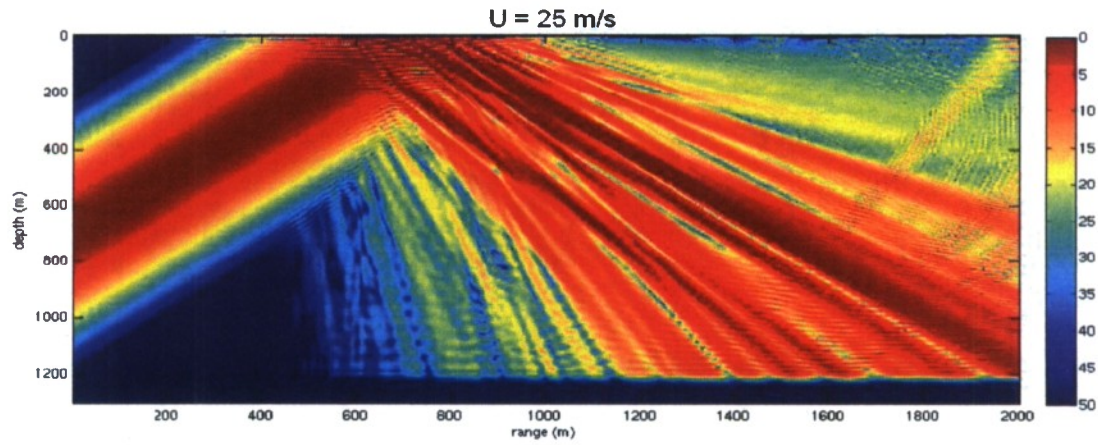


Figure 6: Transmission loss (dB) for a single surface realization. (from Joseph, 2009).

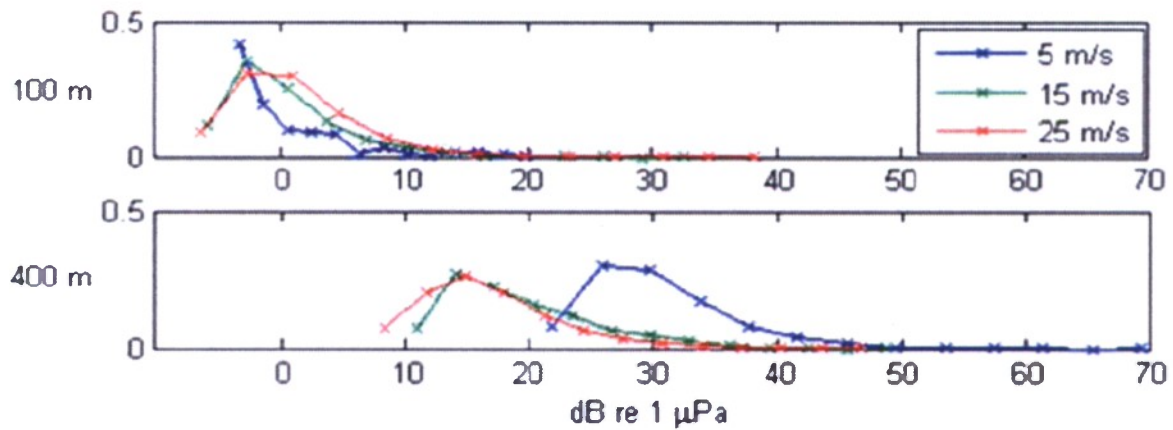


Figure 7: Transmission loss histograms for two depths and three wind speeds. (from Joseph, 2009).

RELATED PROJECTS

None.

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APPENDIX A: PUBLICATIONS

Articles Published in Peer Reviewed Journals

- Ballard, J. A. and R. L. Culver (2009). "The estimated signal parameter detector: Incorporating signal parameter statistics into the receiver," IEEE J. Oceanic Engr. 34 (2), pp. 128-139.
- Culver, R. L. and H.J. Camin (2008). "Sonar signal processing using probabilistic signal and ocean environmental models," J. Acoust. Soc. Am. 124 (6), pp. 3619-3631.

Articles Accepted for Publication in Peer Reviewed Journals

- Bose, N. K., U. Srinivas and R. L. Culver, "Second and Higher Order Whitening of Images in Reconstruction," accepted for publication in the Journal of Telecommunications and Electronics published by the University of Technology and Life Sciences in Bydgoszcz, Poland (September, 2009).

Articles Submitted to Peer Reviewed Journals

- Jemmott, C. W. and R.L. Culver, "Passive sonar source depth classification using model-based amplitude statistics," submitted to IEEE J. Oceanographic Engr (August, 2009).

Referred Conference Proceedings

- Bissinger, B. E., R. L. Culver and N.K. Bose (2009). "Minimum Hellinger Distance based classification of underwater acoustic signals," IEEE CISS 2009, 18-24 March 2009, pp. 47-49.
- Jemmott, C. W., R. L. Culver and N.K. Bose (2008). "Passive sonar target localization using a histogram filter with model-derived priors," IEEE Signals, Systems and Computers 2008, Asilomar, pp. 283-287.

Non-Referred Conference Proceedings

- Jemmott, C. W., R. L. Culver and N. K. Bose (2009). "Modeling Correlation for Passive Sonar Bayesian Localization Techniques," Proc. Meetings on Acoustics (POMA) 6 (1), pp 005002-005002-11 (August 2009).

APPENDIX B: HONORS/AWARDS/PRIZES

Jeff Ballard received the Simowitz Award in 2009 for publishing "The Estimated Signal Parameter Detector: Incorporating Signal Parameter Statistics Into the Signal Processor" in the IEEE J. Oceanic Engineering in January 2009.

Colin Jemmott received the Simowitz Citation in 2009 for presenting the paper "Passive Sonar Target Localization Using a Histogram Filter with a Model-Derived Priors" at the Asilomar Conference on Signals, Systems and Computers, 26-29 October 2008.

Lee Culver was elected Chairman of the Signal Processing Technical Committee of the Acoustical Society of America, a three-year term beginning in the fall of 2009.

DISTRIBUTION LIST

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